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Published in:
Environmental Modelling and Software

DOI:
10.1016/j.envsoft.2017.09.012

Print publication: 09/10/2017

Document Version
Peer reviewed version

What do we know about decision support systems for landscape and environmental management? A review and expert survey within EU research projects

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Abstract

With increasing relevance of transdisciplinary research approaches and impact orientation of scientific achievements, research projects in agricultural landscape management frequently develop information and decision support tools (IS/DSS). An empirical overview on their applicability, user demands and capabilities, functionalities and stakeholder participation in the development process is still lacking. A structured review of projects and an expert survey was carried out to analyse the specific situation of EU-funded research projects. Results reveal certain discrepancy between tool developers' aspirations and outcomes in terms of practitioners targeting. Tools often focus on generic knowledge transfer, but other aspects such as targeted policy and decision-support, longevity, user guidance and involvement are limited. Enhanced integration of end-users in the tool development process and the targeting of a community of practice can help to improve tool usability and applicability. Digital advancement, newly available and integrated data sources offer future opportunities to improve knowledge transfer and decision support.

1 Introduction

Due to globally rising food demand and the scarcity and depletion of natural resources, agricultural productivity and environmental conservation need to be managed simultaneously (Buckwell et al., 2014). The development of information and decision support systems (IS/DSS) is expected to support effective and resource-efficient management of agricultural and environmental systems through the application of a scientifically sound and robust knowledge basis. Decision support tools can help tackling the complexity and trade-offs between agricultural and environmental systems (Manos et al., 2010). Subsequently there has been an increased effort in the recent years to develop frameworks, information platforms and other instruments and processes of knowledge transfer to inform and support decisions in agriculture, landscape and environmental management (Andersson-Sköld et al., 2014; Kersten et al., 2002; McIntosh et al., 2011; McIntosh et al., 2008; Romañach et al., 2014; Tayyebi et al., 2016a; Volk et al., 2010).

In general, IS/DSS are based on the principles of knowledge exchange and transfer, which encompass co-production, transformation and translation of knowledge (Fazey et al., 2013). Through these processes knowledge is transferred from one entity (e.g. place, person, ownership) to another (Major and Cordey-Hayes, 2000) and one of the units is affected by the experience of the other (Argote and Ingram, 2000). Therefore the effectiveness of these systems requires the consideration of (i) the relevant actors and their roles as scientists, stakeholders and end-users, (ii) the knowledge characteristics to be transferred (Hall et al., 2000) as well as (iii) the interface through which knowledge is transferred to end-users. IS/DSS tools connect scientists, stakeholders and end-users, such as policy makers or practitioners, to enable effective transfer of policy-relevant knowledge (King, 2006), methods and operational skills (Kim et al., 2011) and to support evidence-based decision-making (Holmes and Clark, 2008). By providing computer-based interactive, flexible, and user-oriented information, particular IS/DSS aim to facilitate knowledge transfer processes to improve the accessibility to existing knowledge beyond the individual's reach and making it more independent from the relational context (Kim et al., 2011). IS/DSS enable knowledge management activities which often address complex management problems (Sojda, 2007), collaborative information sharing and social and organizational learning (Evers et al., 2016), especially between research and the practice of policy and decision-making. Due to the complexity of the human-environment interaction, the diversity of land use actors, political aspirations and regulations, and the juxtaposition of scientific and practitioner's knowledge, the facilitation of knowledge transfer through IS/DSS in agriculture, landscape and environmental management is particularly important.

However, the extent to which research effectively influences land-use related policy making and practice, e.g. through IS/DSS depends on a number of factors. This includes the relevance, legitimacy and accessibility of the knowledge (Contandriopoulos et al., 2010; de Vente et al., 2016). In addition, Reed et al. (2014) suggest that an adequate representation of the different stakeholders' knowledge needs and priorities, the development of long-term and trusting relationships based on a two-way dialogue between different stakeholders, the delivery of tangible outputs that are of value for (at least some of) the stakeholders and monitoring and reflection on the knowledge transfer process are proposed principles for the successful practice of transferring knowledge. Nevertheless, a low adaptation to user needs and capabilities has been repeatedly found in IS/DSS (van Delden et al., 2011). Often, due to different languages and paradigms within which policymakers and developers operate and by cultural and technical barriers (Tayyebi et al., 2016b). Besides, very few IS/DSS take into account trade-offs both between different ecosystem services and beneficiaries or users and ways of handling these trade-offs. For example, it is easy to imagine users' conflicts with regards to the production and consumption of ecosystem services related to agri-environmental issues such as agricultural non-point pollution, farmland biodiversity, etc. In addition, also the lack of public, inexpensive accessibility to tools and data are limiting the applicability and use of tools (Tayyebi et al., 2016a).

Over the past decade, many research projects in the field of agriculture, environmental and landscape management have developed a wider range of IS/DSS to disseminate accessible and applicable academic knowledge for decision and policy making. These systems and tools differ in the kind of analytic or generic information and type of targeted users, such as land managers, policy makers, stakeholders or scientific community (Kersten et al., 2002; McIntosh et al., 2008). There are also differences regarding the extent to which end-users have been involved within the IS/DSS development process, which has been recognised as a factor influencing their effectiveness.

However oftentimes the experience and knowledge about the IS/DSS development and implementation is rather fragmented among the developers. Beyond small scale comparative analyses of IS/DSS (Lynam et al., 2007; Volk et al., 2010) and empirical surveys among developers (McIntosh et al., 2011), structured reviews of the heterogenic landscape of IS/DSS are seldom in the literature. Few available comparative studies have identified a number of challenges and features, which are critical for the success, including consideration of relevant scales and policy context, engagement with stakeholders and requirements, as well as complexity issues (Denzer, 2005). Users frequently find that the information provided in the IS/DSS does not fit their needs both spatially and regarding the time horizon, precluding of using the tool for decision-making (van Delden et al., 2011). Others examined rather practical features, such as technical requirements, financing, longevity and updating (McIntosh et al., 2011). However, there is only little empirical evidence about the actual situation of IS/DSS tools which have been developed in the past and their compliance with the formulated requirements. To the extent of our knowledge, this study is the first systematic empirical analysis of the different support systems used for complex agricultural and land management decisions.

The objective of this paper is to provide an overview of the IS/DSS tools in the field of agriculture, landscape and environmental management developed within research projects funded by the European Union (EU), assessing common specifications and functionalities of the knowledge transfer, including users interaction during the development, and identifying future development approaches. To this end, a structured review of IS/DSS tools developed during the last ten years as well as a survey among tool developers is carried out. The overall objective is to contribute to the better design of IS/DSS focused on agriculture, landscape and environmental management.

2 IS/DSS in Agriculture, Landscape and Environmental Management

2.1 Characteristics of IS/DSS in the Context of Decision-Making

Due to varying scope of the research, problem and decision context, and type of knowledge to be transferred, a heterogeneous landscape of IS/DSS has emerged. IS/DSS may origin from different disciplinary, methodological and procedural backgrounds and address different regulatory aspects in fields such as urbanisation (Haase et al., 2013), agriculture (Roetter et al., 2007; Tayyebi et al., 2016a) and water and other resource management (Krol et al., 2006; Reichert et al., 2007). IS/DSS are also used for impact assessment of land use decisions (Haase et al., 2010; Tayyebi et al., 2016a), covering various spatial scales from specific site, plot and farm level to entire watersheds (Vorstius and Spray, 2015) and regions (Haase et al., 2013).

IS/DSS often address complex issues with multiple objectives (Krol et al., 2006), thereby integrating research knowledge from several disciplines (Denzer, 2005; van Delden et al., 2011). There are growing pressures from several sides (e.g. funding bodies, academia) to better integrate social and environmental sciences in an interdisciplinary way to address the issues faced by society nowadays (Costanza, 2014; Lemos and Morehouse, 2005; Tress et al., 2003). In the context of our study (i.e. European policy support), those refer in particular to the challenges for a sustainable future of European societies, economies and environment as addressed in the Europe 2020 strategy (COM, 2010). However, IS/DSS operate not only in an interdisciplinary context, but they also have to cross levels of expertise and spatial and temporal scales (Haase et al., 2010).

To address the complexity of the given decision contexts, IS/DSS usually apply various models, databases and assessment frameworks, which are integrated into a software component with a graphical user interface (GUI) (Denzer, 2005). They integrate different analytical approaches, including data-based, dynamic or generic models and algorithms, quantitative and qualitative information covering various analytical (spatial and temporal) scales and technical implementations (De Smedt, 2010). By developing a hierarchy of tools, Booty et al. (2001) have revealed a progression of tools from simple databases, GIS and models, which are rather data and science oriented, to knowledge and policy relevant expert systems, optimization and visualization. Especially in the field of environmental and land use decision-making, IS/DSS systems operate with different scenario options and decision alternatives or elements of those to provide information about possible manoeuvre rooms and ex-ante assessments of decision consequences (Haase et al., 2013; König et al., 2015).

2.2 Stakeholder Participation and Co-production of Knowledge

The main addressees of IS/DSS tools encompass researchers and analysts, land managers, environmental policy and decision-makers as well as land owners and other stakeholders, e.g.

from nature conservation or recreational groups (Rizzoli and Young, 1997). These different types of ‘end-user’ imply specific requirements regarding the rationale and functionality, but have also different capabilities, pre-knowledge and stand points as main users of the knowledge.

Due to both the oftentimes tacit character of knowledge, which is harder to codify and pass on to others through IS/DSS, and the dependency of the user’s cognitive understanding and interpretive capability (King, 2006; McIntosh et al., 2011), the effectiveness of tools depends to a large extent on the way knowledge is conveyed from the source (Garavelli et al., 2002). Therefore, user-targeted design and functionality is often required (Kim et al., 2011) as well as the consideration of the relevant scales and policy domains (van Delden et al., 2011).

An effective IS/DSS application by stakeholders and practitioners, information (and subsequently information systems) needs to be tailored to their particular needs. In this respect, there is agreement about the need of active and timely integration of the different stakeholders in the tool development process (Beunen and Opdam, 2011; Lemos and Morehouse, 2005; van Delden et al., 2011; Voinov and Bousquet, 2010). Involving stakeholders, practitioners and other target groups enhances societal relevance, robustness and real-world feasibility of research knowledge (Zscheischler and Rogga, 2015). This is especially true when complex and multi-faceted issues, such as those related to agricultural landscapes management, focus the IS/DSS. In addition, engagement with key stakeholders increases the probability of stakeholders interpreting and using the research findings effectively (Reed et al., 2014). However, the outputs of these participatory processes will also depend on who participates, how the process is designed and in which context they operate (de Vente et al., 2016). Power imbalances and diversity of viewpoints and perceptions may challenge co-production processes and will require careful consideration by the researchers (Pohl et al., 2010). Particularly, in the field of agri-environmental management, analysts must bear in mind the high risk of power imbalances (e.g. between farmers vs. environmental associations) often present at stakeholder participatory processes.

Legitimate representation of the different ‘knowledges’ increases the opportunities for learning and development of mutual gains (de Vente et al., 2016; Reed, 2008). To this end, integration and cooperation should move beyond only occasional participation to more collaborative and transdisciplinary processes of co-learning and co-creation in the field of tool development (Lynam et al., 2007). Lemos and Morehouse (2005) have emphasised an iterative model of co-production between science and policy. This typically could be carried out in individual phases, e.g. in the beginning of the project for problem identification and target setting, and during model application and tool development for the selection of solutions (Sterk et al., 2009).

In this sense, Voinov et al. (2016) for instance indicates a multitude of possible interaction stages in modelling processes, where stakeholders can actively participate within the research and development process, from scoping and abstraction of concepts and goal setting to application, evaluation and transparency facilitation. In an example of a decision support system in agricultural management, Tayyebi et al. (2016b) integrated developers and scientists from other disciplines, stakeholders and end-users through an interactive participatory process at different stages, from the development and assessment of policy scenarios to the graphical interface development of the DSS, to ensure relevance and applicability.

3 Methodology

To analyse the IS/DSS used within European research projects, we followed a step-wise approach. Firstly, a structured sampling of projects was carried out. Secondly, a document analysis of the available tools was performed with a focus on (i) scale and scope of the problem and decision context, (ii) targeted audience and interaction with end-users, and (iii) tool design, functionality and knowledge type. Thirdly, a survey among tool designers and experts was carried out to elicit information on the IS/DSS development process and to assess individual perceptions regarding tool functionalities, end-user capabilities and previous knowledge, and end-user guidance and interaction.

3.1 Review of Information and Decision Support Systems (IS/DSS)

In the first step, we surveyed research projects which have been funded through the European Commission's 6th (2002-2006) and 7th Research Framework Programmes (2007-2013) to get an overview of the heterogeneity of projects, including (i) the disciplinary classification (i.e. landscape management and planning, agriculture, forestry, nature protection and biodiversity, energy and environment, water management, and transport), and (ii) the research focus on policy intervention, (agricultural) land use and landscape, ecosystem service provision and rural development and regional competitiveness (van Zanten et al., 2014). At this point, we included all suitable projects, regardless the actual IS/DSS existed or not. Particularly in research projects which were further beyond their lifetime, tools did frequently not exist anymore. However, project documents provided some insights into proposed and developed tools.

The CORDIS database[1], which includes all European Commission funded research projects, was used to identify suitable projects by using the specific search terms 'tool', 'decision support' and 'policy support' along with 'landscape', 'agriculture' and 'ecosystem services'. The project search, carried out in July 2014, resulted in a first list of 319 research projects. Information about these research projects was screened and the list was reduced to a total of 60 projects which explicitly developed some kind of knowledge transfer and support platform or planned to do so. A list of these 60 projects is provided in the supplementary material.

In the second step, the review was limited to those research projects for which tools are still available or partly available, with the former referring to on-going projects (with some functions already available and some others not yet) at the time of the survey. In total, 29 out of the 60 projects found in the CORDIS database were reviewed. The remaining cases were either not yet or not anymore available. Based on this list, the analysis could be extended to aspects which are narrowly related to the actual tool or knowledge platform. Table 1 provides an overview of the relevant analysis criteria and respective classifications, which have been derived from previous literature on tool analysis.

Table 1. Analysis criteria and classification.

	Criteria	Classification
Tool scope and rationale	Aim and objective[1]	(i) encourage communication and exchange platform; (ii) information collection and platform; (iii) analytical tool (impact assessment, measurement, etc.); (iv) recommendations, guidelines and best practices.
	Decision orientation	(i) direct; (ii) indirect, supportive through information supply.
	Targeted user group[1]	(i) policy makers; (ii) local planner and decision-maker; (iii) farmer, forester and land manager; (iv) other local stakeholders; (v) wider community and society; (vi) academic community.
Information type	Type of the information	(i) qualitative information and text; (ii) quantitative, numeric information and databases; (iii) visual and audio-visual information.

[1] http://cordis.europa.eu/projects/home_en.html

	provided[1]	
	User interaction	(i) cooperative (the tool offers upload and feedback functions); (ii) active (dynamic, user-specific data analysis and assessments); (iii) passive (provision of generic information, without applicability to user determined parameters).
	Spatial coverage[1]	(i) international and national; (ii) regional: medium territories, landscape, watershed; (iii) local: small areas, farm and plot-level.
Technical characteristics	Technical features[1]	(i) web-based interactive tool; (ii) downloadable software; (iii) database of data or documents.
	Decision context[1]	(i) generic information-type; (ii) filter-type; (iii) calculator-type.
	Complexity	(i) one module; (ii) several modules.
	Degree of integration	(i) integrated into other tool; (ii) cooperation with other tool(s); (iii) no relation with other databases or tools.
	Accessibility	(i) with registration; (ii) without registration.
	User guidance[1]	(i) only introduction site or section; (ii) video guidance; (iii) FAQs; (iv) separated manual; (v) information or help throughout the tool elements.

[1]*Criteria not mutually exclusive. Note: Selection of criteria based on ENRD (2010); McIntosh et al. (2011); Rizzoli and Young (1997).*

3.2 Online Expert Survey

After the literature review, a survey was carried out between August and September 2014 using the online survey software package SoSci Survey[2]. For all 29 projects with available tools, researchers who were either responsible of the project or narrowly involved into the tool development were identified. A list of 116 people was contacted by email, followed by two further reminders. A total of 60 respondents (response rate 52.6%) filled in the questionnaire, with 43 (37.1%) answering to all questions. Responses from 24 out of 29 projects were received (82.8%). The survey captured expert opinions regarding the importance of certain tool functionalities, end-user capabilities and previous knowledge, and corresponding end-user guidance and interaction. Likert-scale questions were applied with value ranges from not important (1), little importance (2), moderately important (3), important (4), and very important (5). Further, multiple response questions (MRQ) were applied to gather information on the kind and extent of stakeholder and end-user involvement in the development process and sustenance of the tool after launch and project end.

[2] https://www.soscisurvey.de/

4 Results

4.1 Overview of the reviewed Research Projects

The review process in the first stage of the study revealed that the number of European research projects, sharply increased between the 6th (16 projects) and 7th Framework Programme (44 projects). Particularly towards the end of the respective programmes (2005, N=7; 2011, N=10), the number of projects particularly increased[3]. Due to the role of the European Commission as a funding organisation, all projects encompass multiple research partners from the EU. In addition, in 41.7% of the cases (N=25) also include partners from non-EU European countries, and in some cases from outside Europe, e.g. Asia (21.7%, N=13).

The reviewed tool-developing research projects showed a wide variety of research and policy topics. Usually more than one specific topic is addressed per project. More than half of the projects focus on land-based production, i.e. agriculture and forestry (58.3%, N=35). Ecology and nature conservation (33.3%), landscape and land use planning (31.7%), management of natural resources such as water and soil (23.3%) as well as energy and climate change (18.3%) represent other important topics of the reviewed projects. A majority of the projects (60.7%) feature a rather broad thematic focus in terms of policy objectives, ecosystem services or public goods addressed. Those projects, such as for instance *LIAISEKIT*[4] or *CAPRI-RD*[5] address a broad range of policy impacts including environmental, economic and social dimensions. Others, such as the knowledge hub of the *HERCULES*[6] project or *GHG-EUROPE*[7] have a much narrower focus on specific questions, such as cultural landscapes or climate mitigation.

For 33 projects (55%) web-based IS/DSS tools have been found partly or fully available, whereas in other cases tools are no longer (N=8) or not yet available (N=14). In five cases, tools are available online, but as desktop software. Regarding the longevity of the IS/DSS systems, the comparison between the overall number of tools provided by the 60 research projects identified and the number actually existing at the time of the review process (July

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[3] The number of tools also depends on the focus of projects calls in the research framework programmes as well as those of the successful projects. Here a clear increasing tendency is observed.
[4] http://www.liaise-kit.eu/content/knowledge-ia
[5] http://www.ilr.uni-bonn.de/agpo/rsrch/capri-rd/overview.htm
[6] http://www.hercules-landscapes.eu/knowledge_hub.php
[7] http://www.europe-fluxdata.eu/

2014) reveals that from all tools developed in projects ending in 2006 (eight years) and later, only 60.7% of the tools still exist. The share increases when considering projects ending between 2010 (78.6%) and 2013 (100%) (see Fig. 1). In addition, only 50% of the tools (N=30) are being updated after the project end. On the other hand, 17 out of 29 on-going projects in 2014 (58.6%) had already available tools.

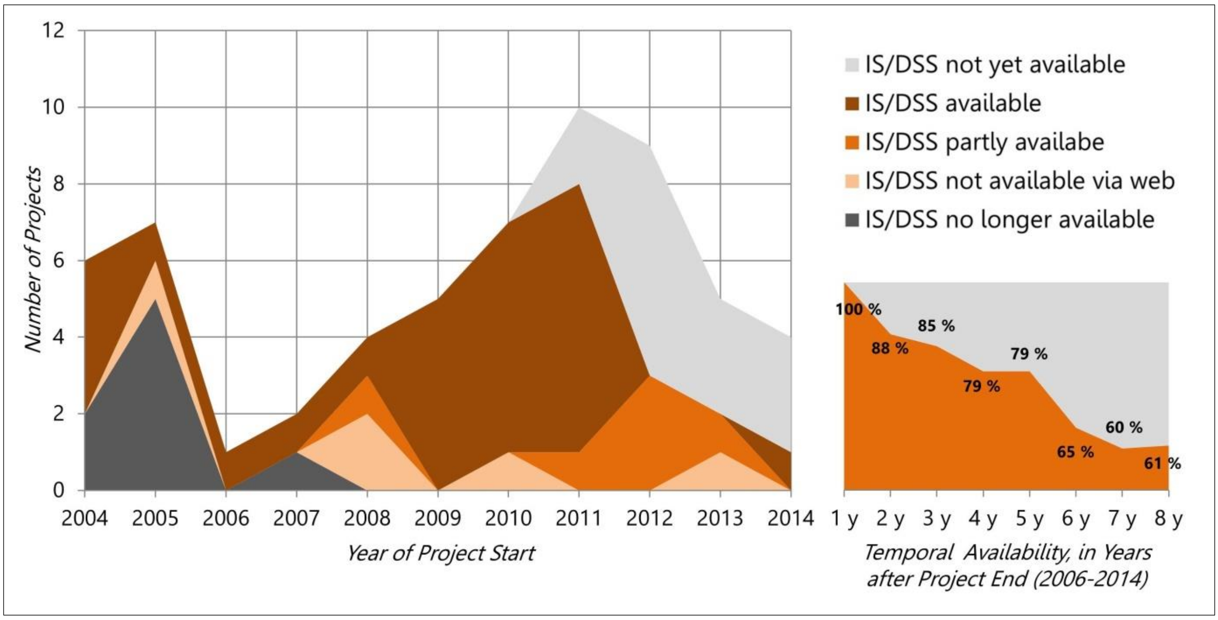

Figure 1. Temporal availability and longevity of online tools.

4.2 Review of EU Research Project IS/DSS

In the second stage of the review process, only those 29 tools which were available at the time of the review have been included into the analysis. These have been analysed regarding (i) the tool scope and rationale, (ii) information type and analysis scale, and (iii) technical characteristics.

4.2.1 Tool Scope and Rationale

Fig. 2 provides an overview of the results regarding the scope and rationale of the IS/DSS surveyed. As shown in this figure, the primary goal of most of the IS/DSS was to provide collected decision-relevant information (79.3%), while other objectives included the communication and exchange of knowledge, the provision of guidelines and best practices and the provision of analysis-tools (found in 37.9%, 31.0%, and 24.1%, respectively). Two examples of IS/DSS aimed at collecting information are the *Balkan Agro Food Network* project[8] tool, which provides an overview of the research activities in agriculture and food science in the Western Balkans, and the *MultiSward* project[9], which compiles a knowledge library of the multifunctionality of grasslands. The vast majority of IS/DSS only addresses the decision-making objective indirectly (82.8%), which means that the tool offers decision-support guidance, instead of providing direct decision support through impact assessments, benchmarks, cost-benefit analysis or the like. Not surprisingly, we found that in project documents it is frequently stated that the tools contribute to creating an evidence-base, understanding complex consequences of possible decision-making and supporting decision-makers. Thus, the minority of projects provide decision-support in the sense of provision of hands-on information for specific land use and management decisions. With regards to the targeted user group, most of the projects target the academic community (62.1%), farmers, foresters and land managers (58.6%), policy makers (58.6%), and local planners and decision-makers (55.2%). On the contrary, few projects target the wider community and society (10.3%).

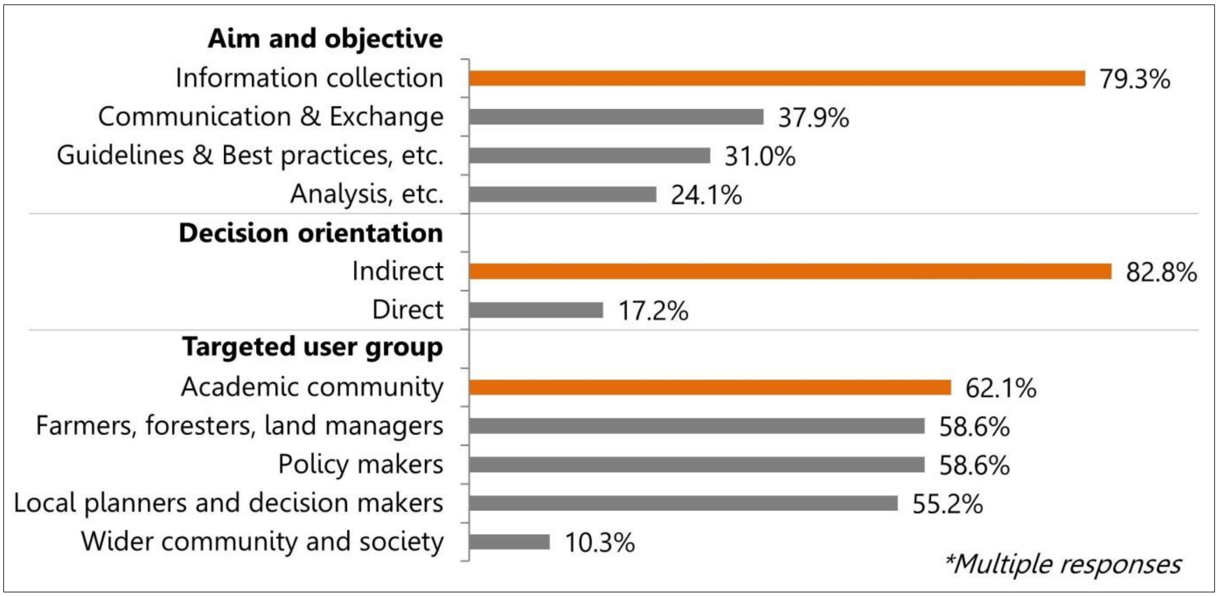

Figure 2. Tool scopes and rationales: aims and objectives, decision orientation, and targeted user group (N=29).

4.2.2 Information Type, User Interaction and Scale

Fig. 3 shows the results of IS/DSS surveyed in function of the information type and scale. The vast majority of IS/DSS include qualitative information (89.7%), while visual and quantitative information are much less provided (31.0% and 24.1%, respectively). An example of the latter

[8] www.bafn.eu
[9] http://appli.poitou-charentes.inra.fr/internet/e-learning/multisward_eng/doku.php

types of IS/DSS is the *CLIMSAVE* project which provided an interactive impact assessment platform[10], enabling users to explore the nexus of vulnerability and adaptation associated with climate change.

With regards to user interaction, there is no type of interaction that clearly stands out, with cooperative and active interaction showing the highest and lowest percentage of IS/DSS (41.4% and 27.6%, respectively). The way the tool interacts with the user is very much driven by the type of information provided and analysis carried out. For instance, an 'active' interaction (i.e. providing and receiving information from the user) is necessary mostly when actual data analysis should be carried out. An example of this type is the *SmartSoil* project[11] which included a IS/DSS developed for farm holders and agricultural advisers targeted to optimise their crop yields and soil carbon content. The tool of the *PanGeo* project[12], which provides access to geographical information database and data interpretations on geohazards for the user-specific location of interest, also falls within this category. A good example of 'cooperative' interaction (i.e. tool offering upload and feedback functions) is the *MultiSward* project as it includes an interactive e-learning component and upload functionalities aiming at enhancing the exchange with stakeholders and farmers to contribute to knowledge collection. However, still there is an important share of the projects (34.5%) with IS/DSS showing passive interaction, so the end-user merely acts as a 'passive' consumer of information, without providing any data input.

Regarding the spatial coverage, many IS/DSS also employ various analytic scales. For instance, the *SPARD information system*[13] provides a pan-European econometric model on needs and effects of rural development policy and a regional case study perspective for a spatial analysis exercise. Nearly 80% of the cases are rather generic of either national or international relevance, whereas 40-50% of the tools surveyed focus regional and local spatial coverages. The *N-TOOLBOX*[14] serves as a representative example of a regionally-based IS/DSS as it provides a catalogue of strategies to cost-effectively reduce nitrogen outtake at regional level.

[10] http://5.2.157.195/IAP/#/Introduction
[11] http://smartsoil.eu/smartsoil-toolbox/about/
[12] http://www.pangeoproject.eu/home
[13] http://sf5.ait.ac.at/spard_site/results/spardisstart.html
[14] http://research.ncl.ac.uk/nefg/ntoolbox/page-tree.php?page=12

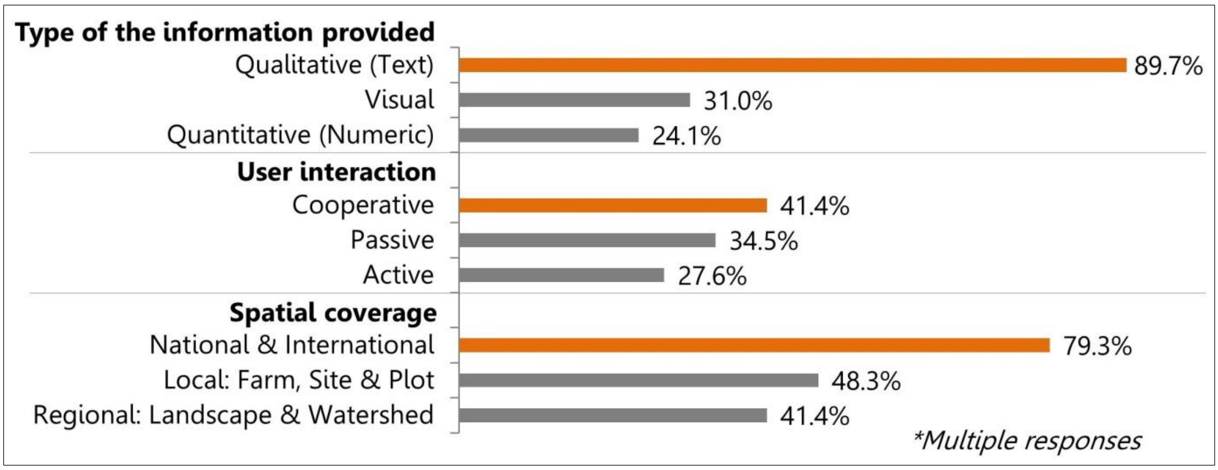

Figure 3. Tool information type: type of information provided user interaction, and spatial coverage (N=29).

4.2.3 Technical Characteristics

An overview of the applied technical and functional properties of IS/DSS tools are presented in Fig. 4. IS/DSS are mostly designed as internet websites (82.8%). Only a minority is implemented as executable software, either online (e.g. through JAVA® or Adobe Flash) or as regular downloadable software. For instance, the research project *HAIR*[15] provides a software programme for risk assessment of agricultural use of pesticides. The data viewer of the *SPARD* information system makes use of an online executable application based on a JAVA® engine to make research results and an indicator database accessible to end-users. Other online platforms such as smartphone applications, widgets, etc. have not been found but a growing development of these platforms is expected in current and future projects.

In most cases (69%) IS/DSS consist of one core module. Others embody a compilation of several modules, often with varying functionalities, scales or addressees. Frequently, they are developed independently from other types. However, 31% of the tools either cooperate with or integrate into others. The *AfroMaison* toolbox[16], which facilitates problem-oriented identification of suitable support tools, represents an example for this type. Rather than being a specific tool itself, the platform serves as a search engine using meta-data. As most tools are information transfer-oriented, few of them clearly show strong analytic functionality, such as the abovementioned cases of *PanGeo* or *SmartSoil*. The application of filtering, such as decision trees, etc. (13.8%) or actual data analysis (37.9%) is on contrast rather less frequent.

[15] http://www.pesticidemodels.eu/hair/home
[16] http://www.afromaison.net/

In addition, 48.3% of the IS/DSS support decision-making by providing only generic information.

In general, most of the reviewed IS/DSS offer easy accessibility to end-users without any restriction (79.3%). In a smaller number of cases, the operators require a registration of the potential user to access the tool. Despite the challenge of information and knowledge transfer from research to policy and practice, comprehensive user-guidance occurs only for a minority of tools. Although in 58.6% of the cases an introductory section is provided, structured support information throughout the different parts of the tool is offered only by 24.1% or a separated manual by 20.7% of the cases. A Frequently Asked Questions (FAQs) section or a video manual is found even more seldom.

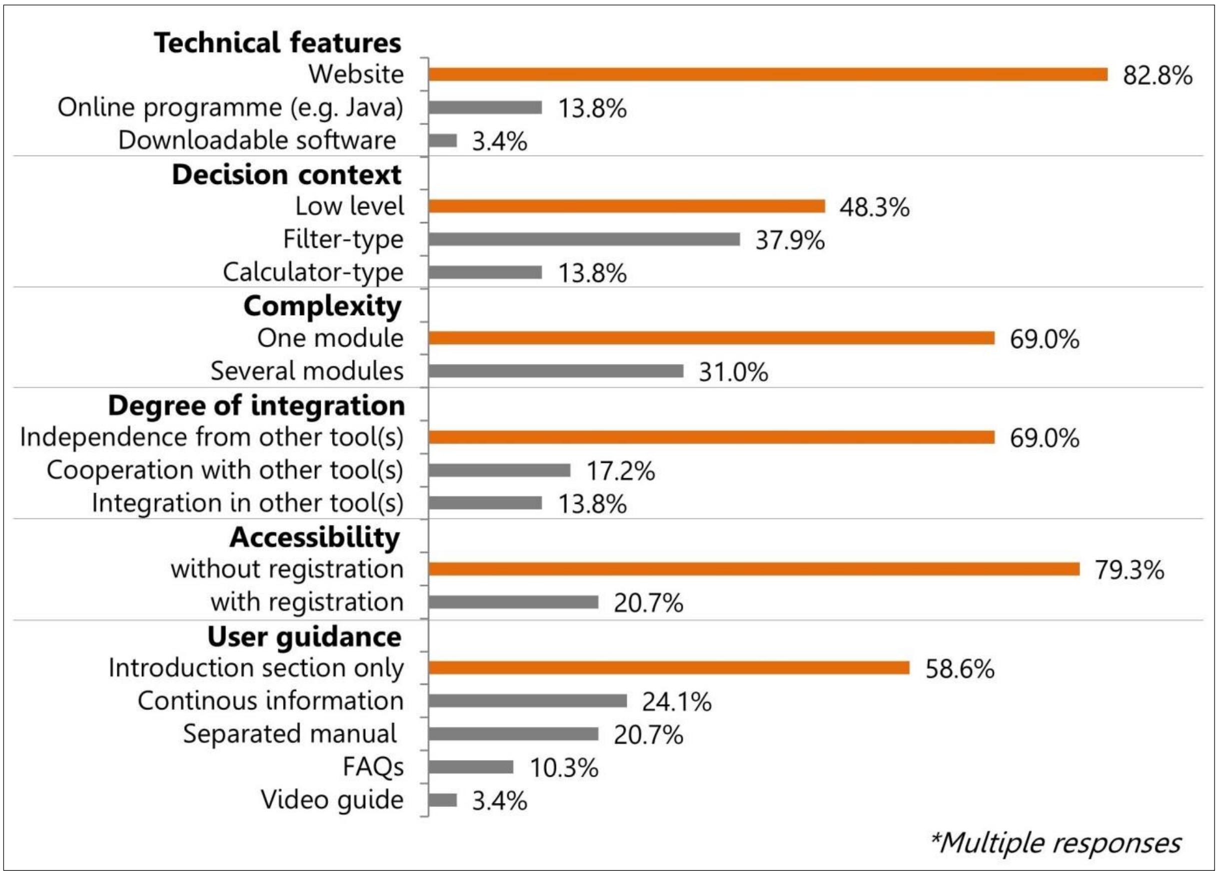

Figure 4. Technical tool characteristics: software IT features, decision context, accessibility, complexity, degree of integration, and user guidance (N=29).

4.3 Expert Survey

Fig. 5 shows the results of the survey among developers and other project experts regarding end-user requirements, the tool rationale, and end-user guidance. Regarding user requirements, developers underlined the ability to interact with the tool (4.00) as important, while the universal accessibility without any restriction (3.88) and pre-knowledge of the potential end-user (3.33) are also seen as relatively important, matching the high open access rates shown above.

Regarding the tool rationales and objectives, the task of enabling communication and exchange within the research-policy-nexus is considered as most important with an average value of 4.24 out of 5. It is followed by the provision of an information platform and guidelines and best practices. While still evaluated as moderately important, the purpose of data analysis has the least relevance from the developers' perspective. This is in line with the previous observations of the general pattern of tool characteristics, where a data-driven approach is significantly underrepresented.

With regards to end-user guidance, interestingly the general pattern of these results corresponds with the results shown in the literature review. Indeed, video manuals (average 2.14, using a Likert-scale) and FAQs (2.61) are of low importance, whereas introductory sections and continuous information play a more important role (3.04 and 3.49).

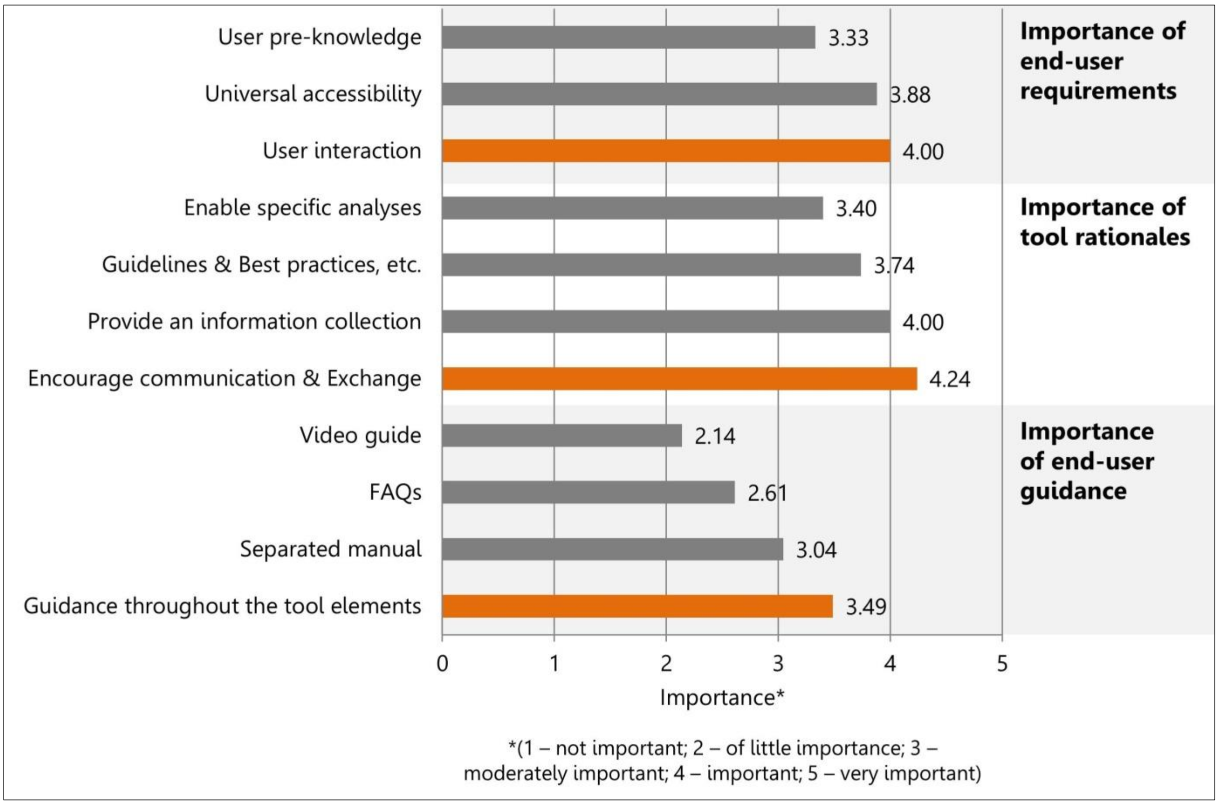

Figure 5. Importance of end-user requirements, tool rationales and user guidance with regards to IS/DSS according to developers and experts (N=29).

Fig. 6 shows the results of the survey with regards to practical application by users. It has been found that nearly 90% of the projects have involved stakeholder within the tool design and development activity. This has been mostly carried out directly in the actual development process (44.8%), more indirectly through a feedback interaction (32.8%) or both. In cases of a participation process, end-users and stakeholders were first of all involved in the definition of the IS/DSS content (76.0%), followed by coordination of the functionality, accessibility and applicability for end-users. According to experts and developers, a large majority of tools are targeted at the academic research community (88.5%) followed by policy makers (77.0%), farmers and land managers (50.8%), and local planners (39.3%), with the general public (29.5%) less often targeted at.

The relevance of the IS/DSS in their practical application by stakeholders, policy and decision-makers, especially beyond the project lifetime shows a rather ambivalent picture (see Fig. 6). An update of the tool and its content after the first launch has been carried out by half of the reviewed projects. In addition, 40.7% of the projects miss out occasional check-ups of the actual usage frequency, so that the developers do not know whether the tool is applied or not. However, most respondents indicated that they actively disseminate their product, often via more than one channel. Conferences and workshops represent an almost universal mean of dissemination and promotion (90.7%). Other frequent options are publications and embedding of links at other internet websites and portals. Search engine optimization is rarely applied.

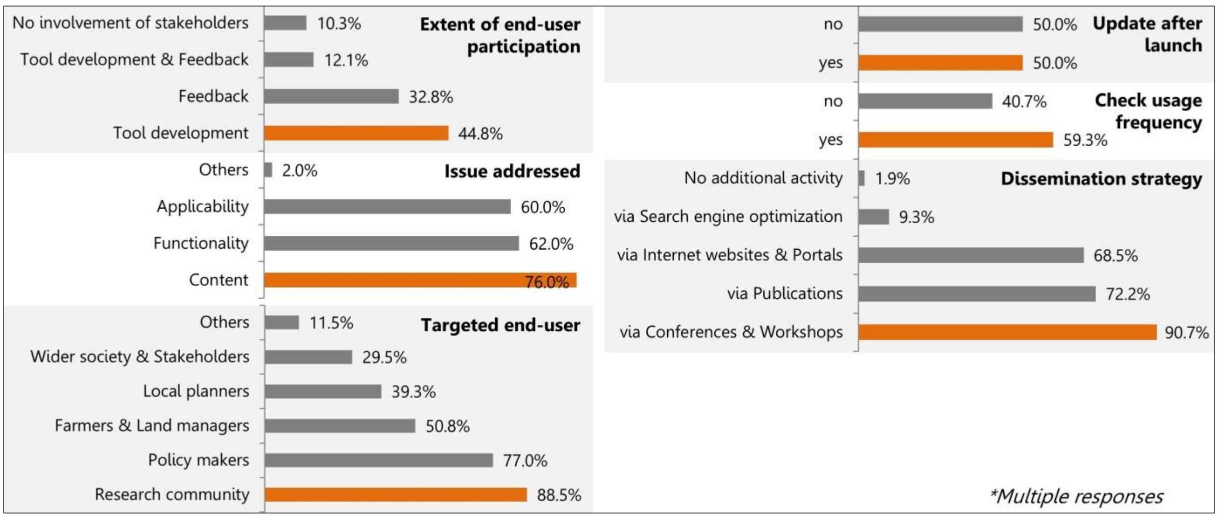

*Figure 6. Practical application by users. Figures indicate percentage of cases (N=29). *Multiple responses.*

5 Discussion

Our paper provides a comprehensive overview of the conceptualisation and implementation of online computer-based information and decision support systems (IS/DSS) in the field of agriculture, environmental and landscape management, and the related policy making. This is done by reviewing European research projects from 6th and 7th Framework Programmes and carrying out a survey among developers and other researchers involved in these projects. Although the study sample is limited to European research projects and experts, these represent a significant share of the overall research activities in IS/DSS development at an international level. However, we are also aware that the wide range of tool developments outside the European research area (see for instance Cash et al., 2003; Manos et al., 2010) as well as at national or regional level examples are missing in the picture. The findings also showed that these international projects tend to address high-level policy-makers and academics, compared to other works developed more locally and with a regional application.

In the review and survey, it was found that the number of tools which have been developed in European research projects has markedly increased throughout the last 10 years. We also found a high diversity of approaches of knowledge transfer, functionalities, scale and scope, but also on the degree of stakeholder involvement and the perspective of experts and developers. Despite this diversity, projects share multiple commonalities. In general, the IS/DSS surveyed frequently consist of knowledge collections and libraries, focusing on qualitative and text-type information of generic and scientific significance rather than being user specific and decision-support oriented. Below some specific features of the IS/DSS surveyed are discussed.

5.1 Tool Functionality to address the Research-Policy-Interface

The IS/DSS under consideration are often of a very academic nature with the research community as prime target group, whereas impact and applicability for policy and even more for practice seems to be underrepresented. It has been also criticised by Lynam et al. (2007) and van Delden et al. (2011), that research models rarely go beyond the research purpose and at the most provide some policy implications, but are not specifically directed towards policy and decision support. However, it became also evident that considerable efforts are made to adapt applicability and functionalities to non-scientific users.

The assumption of ‘EU-decision-makers’ as principle end-users is rarely scrutinized, and often too generally assumed just due to the fact that the EU Commission is the contracting body for the research. Particularly large international research projects seem to have a certain bias in aiming their tools at high-level (European) policy makers and the international academic community (Paracchini et al., 2011). The topics covered, however, often address issues of relevance at local or even farm scale levels of policy and decision-making. The impact on policy design and decision-making is therefore often limited. User-group and scale mismatches could be avoided by broadening the dialogue with national and regional scale end-users, particularly by involving governments’ policy-makers and superior technicians. Especially, in the case of local level IS/DSS, value added through hands-on support for land managers and decision-makers is widely lacking. Though political relevance grows with scale, the direct problem context becomes less specific, and therefore a successful and persisting transfer and implementation of knowledge becomes more difficult. A driver for research information uptake into policy is the existence of specific problems, and the demand for solutions which can be supported by IS/DSS.

The European Commission is well-aware of this situation when asking for more practical impact through the use and dissemination of relevant research output for projects under the EU Horizon 2020 framework programme (COM, 2014). The increasingly required involvement of non-research actors, such as small and medium size enterprises or non-governmental organisations, in research projects and the growing emphasis on generating practical impact, represent important direction settings towards an improved transfer and brokerage of scientific knowledge outside the academia.

However, it is also worth noting that the emphasis of stakeholders’ involvement in the IS/DSS design will also depend on the focus of the research project. For example, if the main purpose is to support the design and implementation of related policies, while it is also useful to involve non-research and non-policy-making actors, it is key to involve policy-makers. In this sense, more effective tools from the policy-making perspective are expected by involving policy-makers in the design stage, thus ensuring that the knowledge exchange process included in the tool fits the policy needs in terms of both time and contents. In addition, it would be useful to adequately recognise the main policy issues (e.g. policy objectives and what resources and actions are required to achieve them) in the tool development process and to make them explicit to the end-users (e.g. farmers and foresters). Particularly, end-users have to be well informed about how the use of IS/DSS would help to achieve those objectives and targets.

Our results also confirm the lack of interactive nature between tool and end-user, previously highlighted by van Delden et al. (2011). One of the main reasons for this relates to the trade-offs between the purposes of providing highly relevant hands-on information for specific situations and having a broad coverage across cases, regions and questions. In addition, the technical challenges of dynamic and interactive tools also require much more efforts on the design, implementation and long-term maintenance, as well as higher resource needs. At the same time, simplicity is a requirement for user uptake of tools (OECD, 2011).

5.2 Longevity and Impact Monitoring

Our results have shown that the longevity of tools developed in research projects is often very limited. While the launch of a tool usually requires three years from the onset of the project, within the same time span after the project end, already one fifth of all tools surveyed were not accessible anymore. However, whereas online tools remain at least for a couple of years subsequent the project end, the actual usage of tools might drop much earlier. It is argued that along with a delayed or cancelled tool development (Díez and McIntosh, 2009), the missing linkage to the community of practice represents a main reason for this (McIntosh et al., 2011). In this respect central actors who act as leaders (‘champions’) are important to enhance the tool application within the community (van Delden et al., 2011). Further, concise planning of future continuity, continuing update of information as well as clear ideas of costs and benefits are required (McIntosh et al., 2011).

5.3 Knowledge, Communication and User-Guidance

In contrast to Díez and McIntosh (2009), who found a positive relationship between pre-knowledge and the degree of tool adoption, our results reveal that the pre-knowledge of end-users is perceived by tool developers as a not very important requirement. Accordingly, developers also think that user-guidance plays only a minor role. These findings suggest an underestimation of knowledge and communication differences between policy-makers and practitioners on the one side and academia on the other. However, pre-knowledge has been found decisive for individual adoption and actual system use levels. In this regard, also the lack of comprehension, both in terms of availability of information in national language and in terms of the technical language and phrasing, can represent a barrier to the effective use of the tool by land managers. Generally, substantial knowledge differences, such as local and traditional, exist among different user groups (Siebert et al., 2008). In addition, some types of knowledge might not be easily transferable or shaped in the appropriate form needed for a particular tool. The acknowledgement of these knowledge differences (e.g. through guidance systems) and the way how knowledge is communicated (academic vs. lay) can contribute to the usability of the tool and eventually overcome communication barriers between researchers and stakeholders (Quinn, 2010). Therefore, tools either need to reduce complexity and design accessible interfaces (McIntosh et al., 2011) or provide guiding materials, such as glossaries or scoping documents (van Delden et al., 2011). Since policy-makers in the field of environmental and land management usually have different knowledge demands, preferences for acquiring, considering and using information, and receive pressures on different issues, appropriate forms of knowledge brokerage should be agreed in advance (Michaels, 2009), in addition to the media allowing for targeted information selection and uptake, e.g. short video formats.

5.4 Stakeholder Engagement in the Development Process

With policy makers, farmers and land managers and to some extent local planners, practitioners and stakeholders belong to the most frequent targeted end-users. At the same time our results suggest that engagement of these end-users is far from being comprehensive. Less than half of the research projects involved stakeholders in some parts of the tool development, and about one third of the projects included stakeholders as part of a feedback process. Over 10% of the reviewed projects did not involve stakeholders at all.

This contrasts research evidence showing that the integration of stakeholder is crucial for the usefulness and appropriation of the tool (Argent and Grayson, 2001; McIntosh et al., 2011; Voinov and Bousquet, 2010). McIntosh et al. (2008) have pointed out that tool design requires understanding the context for which a tool shall be developed. A number of important measures to enhance stakeholder engagement in tool development have been suggested. These include the allocation of sufficient time and resources, institutionalised end-user commitment as well as a review and feedback system with end-users before finalising (McIntosh et al., 2011). In this sense, Argent and Grayson (2001) proposed to include a prototyping process of the tool and its interface to allow end-user to make suggestions, facilitating subsequent adaptations of the tool. A step-forward in tool development engagement would be the mainstreaming of co-construction processes through the explicit recognition of stakeholders' knowledge and demands as well as the design of processes that would enable co-construction to take place (Reed et al., 2014).

Involving stakeholders, practitioners and other target groups enhances societal relevance, robustness and real-world feasibility of research knowledge. However, this has also implications on required new procedures of quality, validity, and reliability control. Zscheischler and Rogga (2015) suggest a comprehensive integration of these individuals throughout the entire research process, including the tool development. In this sense, Mauser et al. (2013) note that transdisciplinary approaches move beyond only occasional participation, especially by following the ideas of collaborative design and production of knowledge. Voinov et al. (2016) for instance indicated a multitude of possible interaction stages in modelling processes, where stakeholders can actively participate within the research and development process, from scoping and abstraction of concepts and goal setting to application, evaluation and transparency facilitation. McIntosh et al. (2011) also highlight the role of capacity building through qualification and training of end-users along with the role of the community of practice for continuing and promoting the tool. As Neef and Neubert (2011) highlight, instead of "romanticizing" local knowledge integration, it should be "as critically examined as scientific knowledge that goes through a rigorous selection process by peer-reviews and constant revision by other scholars".

6 Conclusion

Despite a large number of EU research programme funded efforts to bridge the science-practice gap by developing IS/DSS on agricultural and environmental issues, the expected value added in IS/DSS uptake and impact on end-users seem to fall short. Our results confirm the insufficient involvement of stakeholders and matching of expectations and real impact of tools. Although empirical evidence points to to the need of stakeholder co-development of IS/DSS to unlock their potential, a general top-down approach prevails. Due to both the complexity of real-world phenomena and policy processes, definition of the types, scope and stakes of stakeholders remains challenging. In this context, further efforts are needed to co-design approaches for tool development that improves participation and the science-practice knowledge transfer capacity. The overview of IS/DSS described here calls for an ongoing process of shifting research paradigms towards a transdisciplinary multi-actor engagement, as already recognised in the Horizon 2020 research programme. Especially with the continuing digitalisation also in the field of land-based production and the rise of data gathering technologies (e.g. use of drones), social median and crowd sourcing of information and increasing data availability (“big data”), more comprehensive and interactive knowledge exchange and decision-support will be encouraged. The increasing availability and interlinking of decision-relevant data and their automated application brings large-scale opportunities, but also challenges for the development of IS/DSS tools and integration of stakeholders and ‘knowledges’ at different scales, especially when stakeholders (such as farmers and foresters) are not frequent internet users.

7 Acknowledgments

This paper was supported by the Horizon 2020 Framework Programme project PROVIDE (PROVIding smart DElivery of public goods by EU agriculture and forestry) funded by the European Commission - DG Research & Innovation Grant Agreement Numbers 222738 and 633838).

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